Exclusive production of large invariant mass pion pairs in ultraperipheral ultrarelativistic heavy ion collisions

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Abstract

The cross section for exclusive production of $\pi^+\pi^-$ and $\pi^0\pi^0$ meson pairs in ultrarelativistic heavy ion collisions is calculated for LHC energy $\sqrt{s_{NN}} = 3.5$ TeV taking into account photon-photon mechanism. We concentrate on the production of large two-pion invariant masses where the mechanism of the elementary $\gamma\gamma \to \pi\pi$ process is not fully understood. In order to include a size of nuclei we perform calculation in the impact-parameter equivalent photon approximation (EPA). Realistic charge densities are used to calculate charged form factor of ^{208}Pb nucleus and to generate photon fluxes associated with ultrarelativistic heavy ions. Sizeable cross sections are obtained that can be measured at LHC. The cross section for elementary $\gamma\gamma \to \pi\pi$ is calculated in the framework of pQCD Brodsky-Lepage (BL) mechanism with the distribution amplitude used to descibe recent data of the BABAR collaboration on pion transition form factor, using hand-bag mechanism advocated to describe recent Belle data as well as t and u-channel meson/reggeon exchanges. We present distributions in two-pion invariant mass as well as the pion pair rapidity for the nuclear process.

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I. INTRODUCTION

It was shown in several review articles [1] that the ultrarelativistic collisions of heavy ions provide a nice opportunity to study photon-photon collisions. This is due to the enhancement caused by the large charge of the colliding ions. Parametrically the cross section is proportional to $Z_1^2 Z_2^2$ which is a huge number. It was discussed recently that the inclusion of nuclei sizes as well as realistic charge distributions in nuclei lowers the cross section compared to the naive predictions. Recently we have studied the production of $\rho^0 \rho^0$ pairs [2], of muonic pairs [3], of heavy-quark heavy-antiquark [4] as well as $D\bar{D}$ meson pair [5].

In the present paper we wish to study probably the simplest to measure exclusive production of pionic pairs. The elementary processes $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ have been studied in detail in the past (see e.g. [6]). While very low energies are the domain of the chiral perturbation theory [7], at the intermediate energies one has to include also pionic resonances in the s-channel as well t and u-channel exchanges [6, 8–10]. At low dipion invariant masses a huge contribution could come from a competitive photon–pomeron (pomeron–photon) mechanism of exclusive ρ^0 production and it subsequent decay. The cross section for this process is very large (see e.g. [11]). At even higher energies $\sqrt{s} > 2$ GeV the mechanism of the reaction is not fully understood. Brodsky and Lepage made a first prediction of the leading-order pQCD [12] which was further studied e.g. in [13, 14]. In general, the predictions of the pQCD calculation lay below the experimental data measured at LEP [15] and recently by the Belle collaboration [16]. The next-to-leading order calculation has been carried out only in Ref. [17] and their result is not able to describe the present experimental data. The pQCD amplitude for the $\gamma\gamma \to \pi\pi$ reaction depends on the pion distribution amplitude. It was believed for already some time that the pion distribution amplitude is close to the asymptotic form ($6\,x(1-x)$). This turned out to be inconsistent with recent results of the BABAR collaboration for the pion transition form factor $F_{\gamma^*\gamma\pi}$ for large photon virtualities [18]. The authors of Ref. [19] used a new model of the distribution amplitude which can describe the BABAR data. We shall use this model for the $\gamma\gamma \to \pi\pi$ reaction.

Some time ago Diehl, Kroll and Vogt (DKV) suggested that a soft hand-bag mechanism may be the dominant mechanism [20] for wide-angle scattering at intermediate energies. In this approach the normalization as well as energy dependence of the corresponding cross section are adjusted to the world-data on the $\gamma\gamma \to \pi^+\pi^-$ production [20].

In the present paper first we show how the different mechanisms describe the elementary data. Next we present our predictions for the nucleus-nucleus collisions. We will show distributions in the dipion invariant mass as well as in the pion pair rapidity. These are quantities which can be easily calculated in the impact-parameter equivalent photon approximation (b-space EPA).

II. ELEMENTARY CROSS SECTION FOR $\gamma\gamma \to \pi\pi$

A. Perturbative QCD approach

Basic diagrams of the Brodsky and Lepage formalism are shown in Fig. 1. The invariant amplitude for the initial helicities of two photons can be written as the following convolution:

$$\mathcal{M}\left(\lambda_1, \lambda_2\right) = \int_0^1 dx \int_0^1 dy\, \phi_\pi\left(x, \mu_x^2\right) T_H^{\lambda_1\lambda_2}\left(x, y, \mu^2\right) \phi_\pi\left(y, \mu_y^2\right), \qquad (2.1)$$
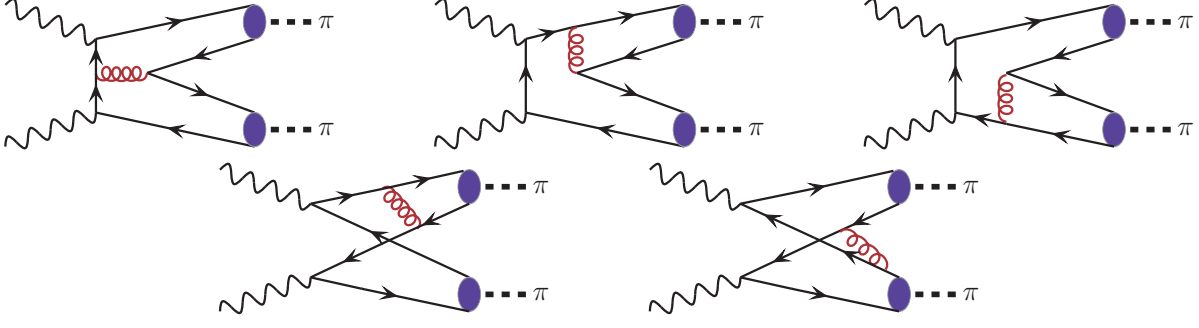
FIG. 1: Feynman diagrams describing the $\gamma\gamma \to (q\bar{q})(q\bar{q}) \to \pi\pi$ amplitude in the LO pQCD.

where $\mu_x = min\,(x, 1-x)\sqrt{s(1-z^2)}$, $\mu_y = min\,(y, 1-y)\sqrt{s(1-z^2)}$; $z = \cos\theta$ [12]. We take the helicity dependent hard scattering amplitudes from Ref. [13]. These scattering amplitudes are different for $\pi^+\pi^-$ and $\pi^0\pi^0$. It was proposed in Ref. [21] to exclude the region of small Mandelstam t and u variables by multiplying the pQCD amplitude (2.1) by an extra form factor which cuts off the soft regions which were taken into account in Ref. [21] explicity by including meson exchanges. The following form of the form factor was proposed in [21]:

$$F_{reg}^{pQCD}(t, u) = \left[1 - \exp\left(\frac{t - t_m}{\Lambda_{reg}^2}\right)\right]\left[1 - \exp\left(\frac{u - u_m}{\Lambda_{reg}^2}\right)\right], \tag{2.2}$$

where $t_m = u_m$ are the maximal kinematically allowed values of t and u. Λ_{reg} is a cut-off parameter expected to be of the order of 1 GeV. The distribution amplitudes are subjected to the ERBL pQCD evolution [22, 23]. The scale dependent quark distribution amplitude of the pion [24, 25] can be expanded in term of the Gegenbauer polynomials:

$$\phi_\pi\left(x, \mu^2\right) = \frac{f_\pi}{2\sqrt{3}} 6x\,(1-x)\sum_{n=0}^{\infty}{}' C_n^{3/2}\,(2x-1)\,a_n\left(\mu^2\right), \tag{2.3}$$

where the expansion coefficients (only even above) can be written as:

$$a_n\left(\mu^2\right) = \frac{2}{3}\frac{2n+3}{(n+1)(n+2)}\left(\frac{\alpha\left(\mu^2\right)}{\alpha\left(\mu_0^2\right)}\right)^{-\frac{C_F}{\beta_0}\left[3 + \frac{2}{(n+1)(n+2)} - 4\sum_{k=1}^{n+1}\frac{1}{k}\right]}\int_0^1 dx\,C_n^{3/2}\,(2x-1)\,\phi_\pi\left(x, \mu_0^2\right), \tag{2.4}$$

where $\beta_0 = \frac{11}{3}C_A - \frac{2}{3}N_F$, $\alpha_s\left(\mu^2\right) = \frac{4\pi}{\beta_0\ln\frac{\mu^2}{\Lambda_{QCD}^2}}$, $C_n^{3/2}$ denote the Gegenbauer polynomials,

$C_F = \frac{4}{3}$, $C_A = 3$, N_F is the number of active quarks and Λ is the QCD scale parameter.

Different distribution amplitudes have been used in the past [12, 25, 26]. Wu and Huang [19] proposed recently a new distribution amplitude (based on a certain light-cone wave function):

$$\phi_\pi\left(x, \mu_0^2\right) = \frac{\sqrt{3}A\,m_q\beta}{2\sqrt{2}\pi^{3/2}f_\pi}\sqrt{x\,(1-x)}\left(1 + B \times C_2^{3/2}\,(2x-1)\right)$$

$$\times \left(\mathrm{Erf}\left[\sqrt{\frac{m_q^2 + \mu_0^2}{8\beta^2 x\,(1-x)}}\right] - \mathrm{Erf}\left[\sqrt{\frac{m_q^2}{8\beta^2 x\,(1-x)}}\right]\right). \tag{2.5}$$

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This pion distribution amplitude at the initial scale is controlled by the parameter B. It has been found that the BABAR data at low and high energy regions can be described by setting B to be around 0.6. This pion distribution amplitude is rather close to the well know Chernyak-Zhitnitsky [27] distribution amplitude ($\phi_{\pi CZ} = 30x(1-x)(2x-1)^2$). In the following (Eq. 2.5) we shall use $B = 0.6$ and $m_q = 0.3$ GeV. Then $A = 16.62$ GeV^{-1} and $\beta = 0.745$ GeV. f_π above is the pion decay constant.

The total (angle integrated) cross section for the process can be expressed in terms of the amplitude of the process discussed above as:

$$\sigma\left(\gamma\gamma \to \pi\pi\right) = \int \frac{2\pi}{4 \cdot 64\pi^2 W^2} \frac{p}{q} \sum_{\lambda_1,\lambda_2} \left|\mathcal{M}\left(\lambda_1, \lambda_2\right)\right|^2 dz \;, \tag{2.6}$$

where the factor 4 is due to averaging over initial photon helicities.

B. Hand-bag model

The hand-bag model was proposed as an alternative for the leading term BL pQCD approach [20]. It is based on the philosophy that the present energies are not sufficient for the dominance of the leading pQCD terms. As in the case of BL pQCD the hand-bag approach applies at large Mandelstam variables $s \sim -t \sim -u$ i. e. at large momentum transfers. Diehl, Kroll and Vogt presented a sketchy derivation [20] obtaining that the angular dependence of the amplitude is $\propto 1/\sin^2 \theta$. Then the cross section integrated over $\cos\theta$ from $-\cos\theta_0$ to $\cos\theta_0$ for a charged pion pairs takes the simple form:

$$\sigma\left(\gamma\gamma \to \pi^+\pi^-\right) = \frac{4\pi\alpha_{em}^2}{s}\left(\frac{\cos\theta_0}{\sin^2\theta_0} + \frac{1}{2}\ln\frac{1+\cos\theta_0}{1-\cos\theta_0}\right)\left|R_{\pi\pi}\left(s\right)\right|^2. \tag{2.7}$$

Additionally, the ratio of the cross section for the $\pi^0\pi^0$ process to the $\pi^+\pi^-$ process doesn't depend on θ and is $\frac{1}{2}$. The nonperturbative object $R_{\pi\pi}\left(s\right)$ describing transition from a quark pair to a meson pair cannot be calulated from first principles. In Ref. [20] the form factor was parametrized in terms of the valence and non-valence form factors as:

$$R_{\pi\pi}\left(s\right) = \frac{5}{9s}a_u\left(\frac{s_0}{s}\right)^{n_u} + \frac{1}{9s}a_s\left(\frac{s_0}{s}\right)^{n_s}, \tag{2.8}$$

where the authors of [20] have chosen $s_0 = 9$ GeV^2. The a_u, n_u, a_s and n_s values found from the fit in Ref. [20] slightly depend on energy. For simplicity we have averaged these values and used in the present calculations: $a_u = 1.375$ GeV^2, $n_u = 0.4175$, $a_s = 0.5025$ GeV^2 and $n_s = 1.195$. The hand-bag approach was criticised in Ref. [26].

C. Meson exchanges in t or u channels

Since several mesons (ρ, ω, a_1, a_2, b_1) decay into $\gamma\pi$ channels this means that t and/or u channel exchanges of their virtual (space-like) counterparts may be important for the $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ reactions. As an example in the following we consider ω exchange for the $\pi^0\pi^0$ channel. ρ meson exchange also contributes to this reaction but its contribution is much lower (the corresponding coupling constant is 3 times smaller than that

for ω meson exchange and it enters here in the second power already in the amplitude). So far the exchange of the tensor mesons was not discussed in detail in the literature.

The amplitude for the $\gamma\gamma \to \pi\pi$ reaction via vector meson exchange can be calculated by means of standard Feynman rules assuming tensorial form of the $V\pi\gamma$ coupling. The corresponding coupling constant can be obtained by fitting $V \to \pi\gamma$ decay width. A simple and compact formula for the omega meson exchange amplitude was presented e.g. in Ref. [10]. It can be written as:

$$\mathcal{M}\left(\lambda_1, \lambda_2\right) = \frac{\alpha_{em} h_\omega^2}{16}\left(X_t\left(\lambda_1, \lambda_2\right) + X_u\left(\lambda_1, \lambda_2\right)\right), \tag{2.9}$$

$$X_t\left(\lambda_1, \lambda_2\right) = \frac{\epsilon_1\left(\lambda_1\right)\epsilon_2\left(\lambda_2\right)\left\{t\left(s - u\right) + m_\pi^4\right\} - 2s\left\{\epsilon_1\left(\lambda_1\right)p_1\right\}\left\{\epsilon_2\left(\lambda_2\right)p_2\right\}}{t - m_\omega^2} F_\omega^2\left(t\right), \tag{2.10}$$

$$X_u\left(\lambda_1, \lambda_2\right) = \frac{\epsilon_1\left(\lambda_1\right)\epsilon_2\left(\lambda_2\right)\left\{u\left(s - t\right) + m_\pi^4\right\} - 2s\left\{\epsilon_1\left(\lambda_1\right)p_1\right\}\left\{\epsilon_2\left(\lambda_2\right)p_2\right\}}{u - m_\omega^2} F_\omega^2\left(u\right), \tag{2.11}$$

where the size of the radiative coupling was obtained from the ratiative decay $\omega \to \pi^0\gamma$. In contrast to Ref. [10] we include also vertex form factors $(F_\omega(t), F_\omega(u))$ which take into account the extended nature of the particles involved off-shell effects as well as high-energy reggezation. Not including the form factors leads, in our opinion, to nonphysical results, especially at large energies. Above $W > 1.5$ GeV the so-calculated cross section would significantly exceed experimental data. This point was not disccued in the literature as previous analyses were limited to rather low energies where the problem was not visible (note a remark in Ref. [6]).

Using a vector particle propagators at high energy is not sufficient and one has to include reggezation. This is included in our calculation by multiplying the t and/or u-exchange amplitudes by the extra energy dependent factors:

$$F_\omega\left(t/u\right) = \exp\left(\frac{t/u - m_\omega^2}{2\Lambda_\omega^2}\right)\left(\frac{s}{s_0}\right)^{\alpha(t/u)-1}. \tag{2.12}$$

The ω trajectory is parametrized as $\alpha(t/u) = 0.64 + 0.8\,t/u$ [28] and $s_0 = 1$ GeV is taken in further calculations.

D. Results

In Fig. 2 we show the predictions of the hand-bag approach (solid lines), reggeized ω - exchange (dotted lines) and the Brodsky - Lepage pQCD approach (dashed lines) for angular distributions of the $\gamma\gamma \to \pi^0\pi^0$ reaction for $W = 2.02,\ 2.26,\ 3,05\ 3.95$ GeV. The pQCD results have been calculated in the case when $F_{reg}^{pQCD} = 1$. The cut-off parameter Λ_ω in Eq. (2.12) was taken to be $\Lambda_\omega = 1$ GeV. The results of different calculation are confronted with the Belle data. For the energies of present experiments the pQCD result is well below the experimental data. As can be seen from the figure the ω - exchange may play a role only at large $|\cos\theta|$. The result of the hand-bag approach starts to describe the data at energies $\sqrt{s} > 3$ GeV.

In Fig. 3 we compare the pQCD $\gamma\gamma \to \pi\pi$ cross section for the pion distribution amplitude with and without pQCD evolution. The effect of the pQCD evolution on the angle-integrated cross section is very small, practically negligible. The data correspond to limited
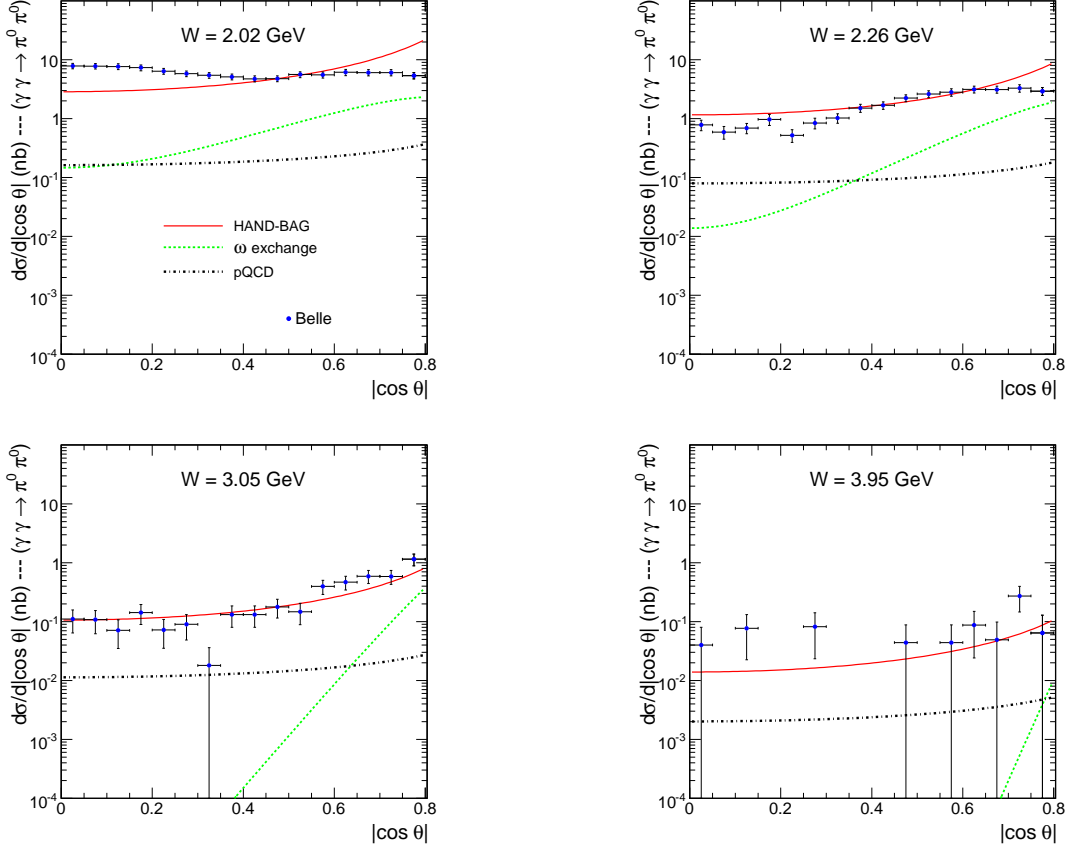
FIG. 2: Angular distributions for the $\gamma\gamma \to \pi^0\pi^0$ reaction. The experimental data are taken from Ref. [29].

angular ranges given in the figure. The data for the $\gamma\gamma \to \pi^+\pi^-$ reaction are from the ALEPH [15], Belle [16], CELLO [30], CLEO [31], Gamma [32], Mark II [33] and VENUS [34] Collaborations. For the $\gamma\gamma \to \pi^0\pi^0$ reaction we present the Belle [35] and Crystall Ball [36] data.

In Fig. 4 we show the predictions of the hand-bag approach [20] together with modern experimental data. The predictions can be taken seriously above the resonance region, i.e. when $\sqrt{s_{\gamma\gamma}} > 2.5$ GeV. The parameters of the hand-bag contribution were adjusted to somewhat older experimental data. One can see that the hand-bag approach, while consistent with the $\pi^+\pi^-$ data, slightly overestimates the $\pi^0\pi^0$ data.

In Fig. 5 we show the ratio of the cross section for the $\gamma\gamma \to \pi^0\pi^0$ process to that for the $\gamma\gamma \to \pi^+\pi^-$ process. The dashed line represents the hand-bag model [20] result and the solid lines is for the Brodsky-Lepage pQCD approach. For larger range of $z = \cos\theta$ the ratio is smaller which means that the ratio is z dependent. The ratio is practically independent of the collision energy. In the present calculations, the z-averaged ratio for $|\cos\theta| < 0.6$ is about 0.2. The experimental error bars for the ratio (only statistical) were obtained with the help of the following formula:

$$\Delta\left(\frac{\sigma(\pi^0\pi^0)}{\sigma(\pi^+\pi^-)}\right) = \sqrt{\left(\frac{1}{\sigma(\pi^+\pi^-)}\right)^2 \Delta^2\sigma(\pi^0\pi^0) + \left(\frac{\sigma(\pi^0\pi^0)}{\sigma^2(\pi^+\pi^-)}\right)^2 \Delta^2\sigma(\pi^+\pi^-)}. \qquad (2.13)$$
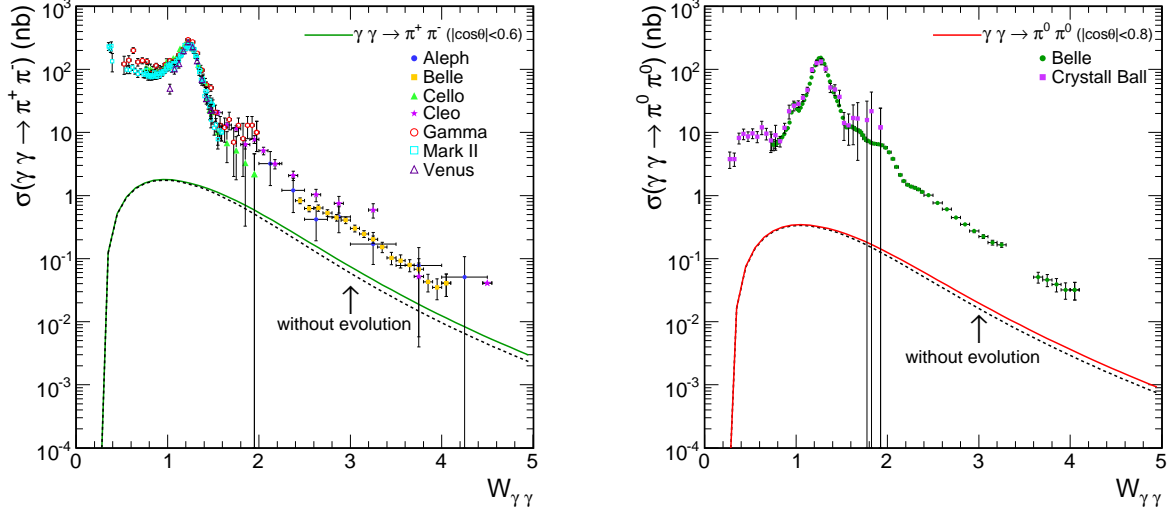
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FIG. 3: The pQCD cross section for $\gamma\gamma \to \pi^+\pi^-$ (left panel) and for $\gamma\gamma \to \pi^0\pi^0$ (right panel) as a function of photon-photon energy. The solid lines show the results for evolved $\phi_\pi(x, \mu^2)$ and the dashed lines are for $\phi_\pi(x, \mu_0^2)$ where $\mu_0^2 = 0.25$ GeV^2 was chosen.

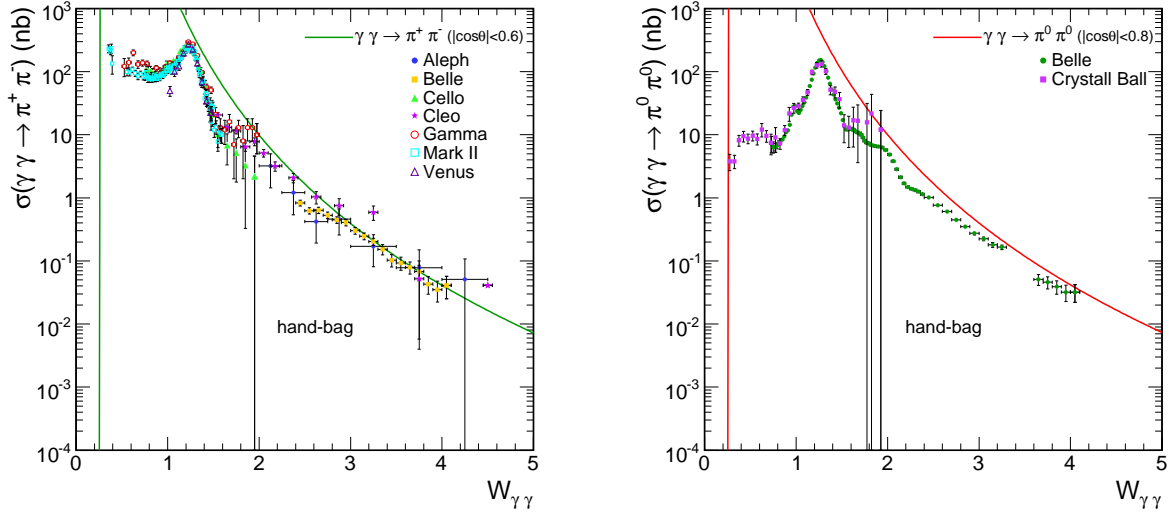FIG. 4: The hand-bag contribution for $\gamma\gamma \to \pi^+\pi^-$ (left panel) and for $\gamma\gamma \to \pi^0\pi^0$ (right panel) as a function of photon-photon energy.

The experimental data points are in between the predictions of the BL pQCD approach and the hand-bag model which further clouds the situation.

III. THE NUCLEAR CROSS SECTION FOR THE PION PAIR PRODUCTION

In our opinion the equivalent photon approximation in the impact parameter space (b-space EPA) is the best suited approach for applications to the peripheral collisions of nuclei.
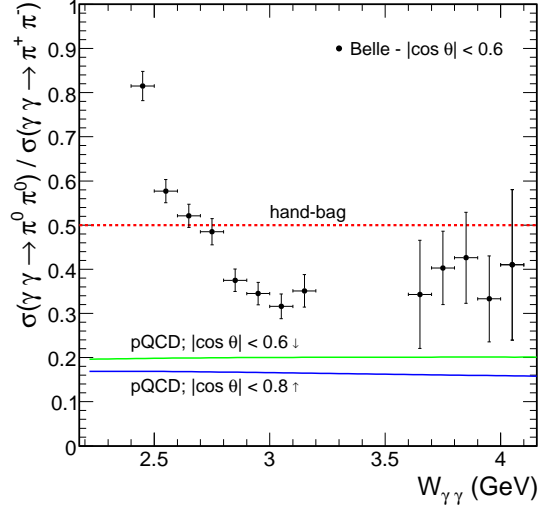
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FIG. 5: Ratio of the cross section for the $\gamma\gamma \to \pi^0\pi^0$ process to that for the $\gamma\gamma \to \pi^+\pi^-$ process. The experimental data were obtained based on the original Belle Colaboration [16, 35] data as explained in the text.
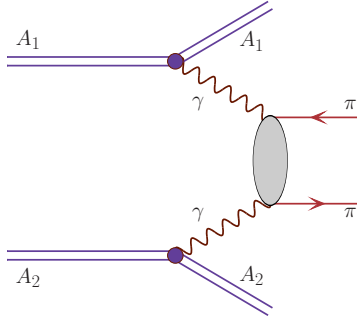

FIG. 6: The Feynman diagram illustrating the formation of the pion pair as a result of the peripheral nuclear collision.

In this approach absorption effect can be taken into account easily by limiting impact parameter $b > R_1 + R_2 \approx 14$ fm. This approach have been used recently in the calculation of the muon pairs or $\rho^0\rho^0$ pairs. The details of the b-space EPA have been described in [2, 3]. Below we present a useful and compact formula for calculating the total cross section for the considered process:

$$\sigma\left(PbPb \to PbPb\pi\pi; W_{\gamma\gamma}\right) = \int \hat{\sigma}\left(\gamma\gamma \to \pi\pi; W_{\gamma\gamma}\right) \theta\left(|\mathbf{b}_1 - \mathbf{b}_2| - 2R_A\right)$$

$$\times N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) 2\pi b\,\mathrm{d}b\,\mathrm{d}\overline{b}_x\,\mathrm{d}\overline{b}_y \frac{W_{\gamma\gamma}}{2}\mathrm{d}W_{\gamma\gamma}\mathrm{d}Y \quad , \qquad (3.1)$$

where the quantities $N\left(\omega, \mathbf{b}\right)$ can be interpreted as photon fluxes associated with each of the nucleus and $\overline{b}_x, \overline{b}_y$ are auxiliary quantities which have been introduced in [4]. The photon flux is expressed in terms of the charge form factor.

In Fig. 7 we show the modulus of the charge form factor of the ^{208}Pb nucleus for realistic charge distribution. The oscillations are related to relatively sharp edge of the nucleus.
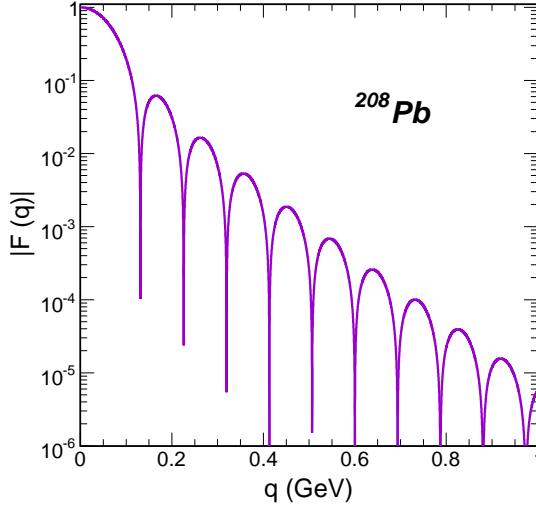
FIG. 7: The modulus of the charge form factor of the ^{208}Pb nucleus for realistic charge distribution.

Let us come now to our predictions of the nuclear cross sections. In Fig. 8 we show distribution in the two-pion invariant mass which by the energy conservation is also the photon-photon subsystem energy. For this figure we have taken experimental limitations usually used for the $\pi\pi$ production in e^+e^- collisions. In the same figure we show our results for the $\gamma\gamma$ collisions extracted from the e^+e^- collisions together with the corresponding nuclear cross sections for $\pi^+\pi^-$ (left panel) and $\pi^0\pi^0$ (right panel) production. We show the results for the standard BL pQCD approach and for the approach proposed in Ref. [20] where an extra form factor given by Eq. (2.2) was used to remove nonperturbative regions of small-angle scattering described at low energy in terms of meson exchanges. One can see that a difference occurs only at small energies which is not the subject of the present analysis. Above $\sqrt{s_{NN}} > 3$ GeV the two approaches coincide. By comparison of the elementary and nuclear cross sections we see a large enhancement of the order of 10^4 which is somewhat less than $Z_1^2 Z_2^2$ one could expect from a naive counting.

In the e^+e^- collisions the cuts on $z = \cos\theta$ are usually different for $\pi^+\pi^-$ than for $\pi^0\pi^0$. In the left panel of Fig. 9 we show the nuclear cross section for the same cut on z. In the Brodsky-Lapage pQCD approach the cross section for $\pi^+\pi^-$ production is about order of magnitude larger than that for the $\pi^0\pi^0$ production. This is very different than for the hand-bag approach where the ratio is just $\frac{1}{2}$. As already commented above one can trust the pQCD results only for not too small energies and not too small angles or equivalently for not too small transverse momenta of pions. In the right panel we compare results of the Brodsky-Lepage pQCD approach (solid line) and results of the hand-bag approach (dashed line). Here in order to ensure validity of the both approaches we have imposed extra cuts on pion transverse momenta ($p_t > 3$ GeV). At lower energies ($W < 14$ GeV) the hand-bag cross section is bigger than the cross section for the Brodsky-Lepage pQCD for the $\pi^+\pi^-$ production and the situation reverses at higher enrgies. For the $\pi^0\pi^0$ production the hand-bag cross section is always bigger than the BL pQCD cross section in the shown energy range. In this case the measured cross sections are not too big but should be measurable.

As shown before the hand-bag approach better describes the elementary cross section. Therefore the hand-bag approach is used to estimate nuclear cross section. In the left panel
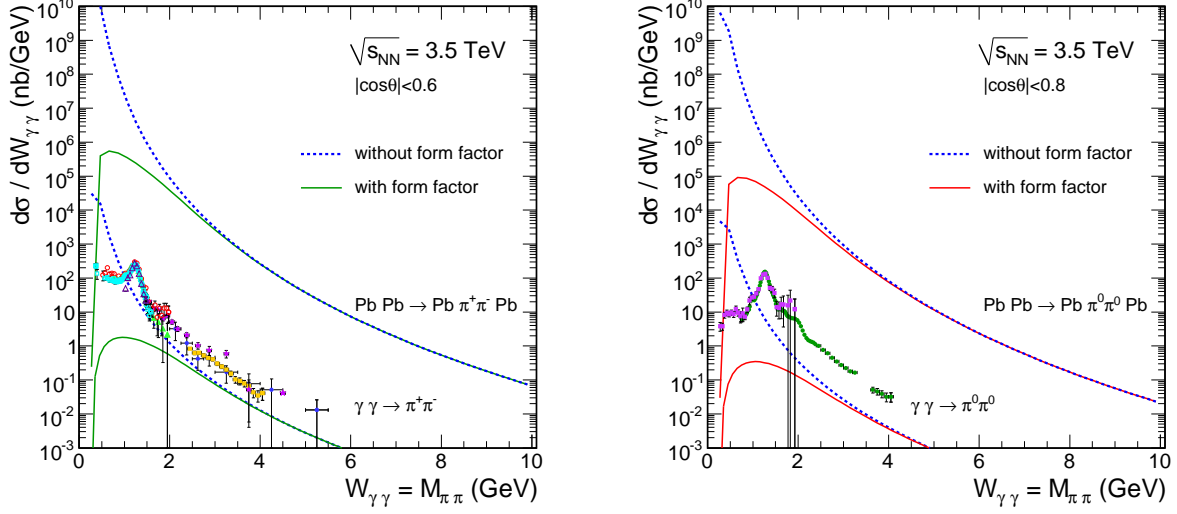
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FIG. 8: The nuclear (upper lines) and elementary (lower lines) cross section as a function of photon–photon subsystem energy $W_{\gamma\gamma}$ in the b-space EPA within the BL pQCD approach for the elementary cross section with Wu-Huang distribution amplitude. The angular ranges in the figure caption correspond to experimental cuts.
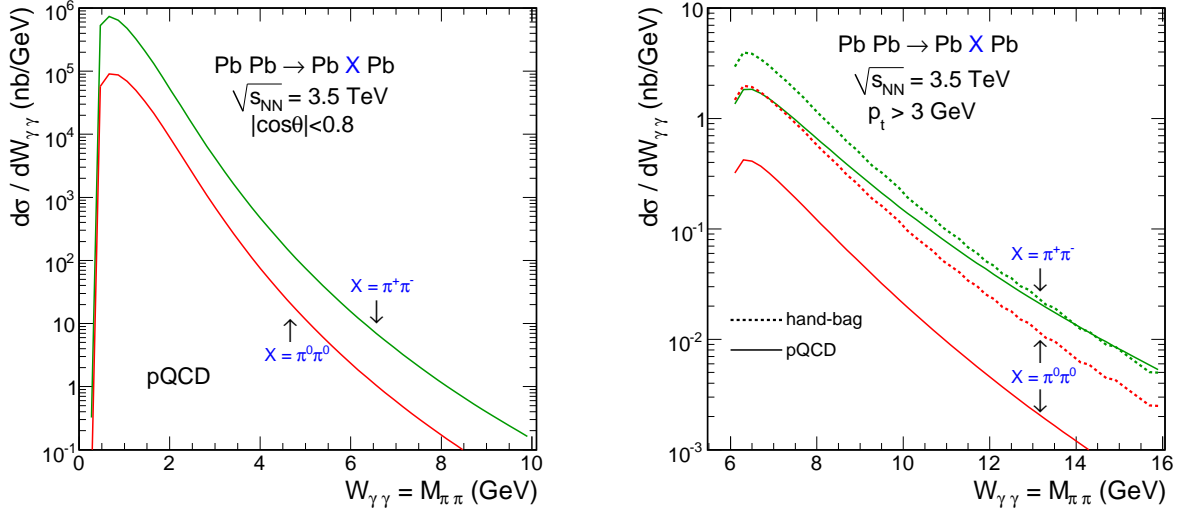

FIG. 9: The nuclear cross section as a function of the $\gamma\gamma$ subsystem energy for the $PbPb \to PbPb\pi^+\pi^-$ (green lines) and for the $PbPb \to PbPb\pi^0\pi^0$ (red lines) reactions calculated for $|\cos\theta| \leq 0.8$ (left panel) and with an extra cut–off on pion transverse momentum $p_t > 3$ GeV (right panel).

of Fig. 10 we show pion pair rapidity distributions for different cuts. We hope that this figure may be a useful estimate of the cross sections for possible future experiments. In the right panel of Fig. 10 we compare the results of the BL pQCD approach and of the hand-bag approach for $p_t > 3$ GeV (which by kinematics is equivalent to $W_{\gamma\gamma} > 6$ GeV). This is a region which was not measured so far in the e^+e^- collisions. Nuclear experiment in this region should therefore discriminate between the two approaches. One could measure either
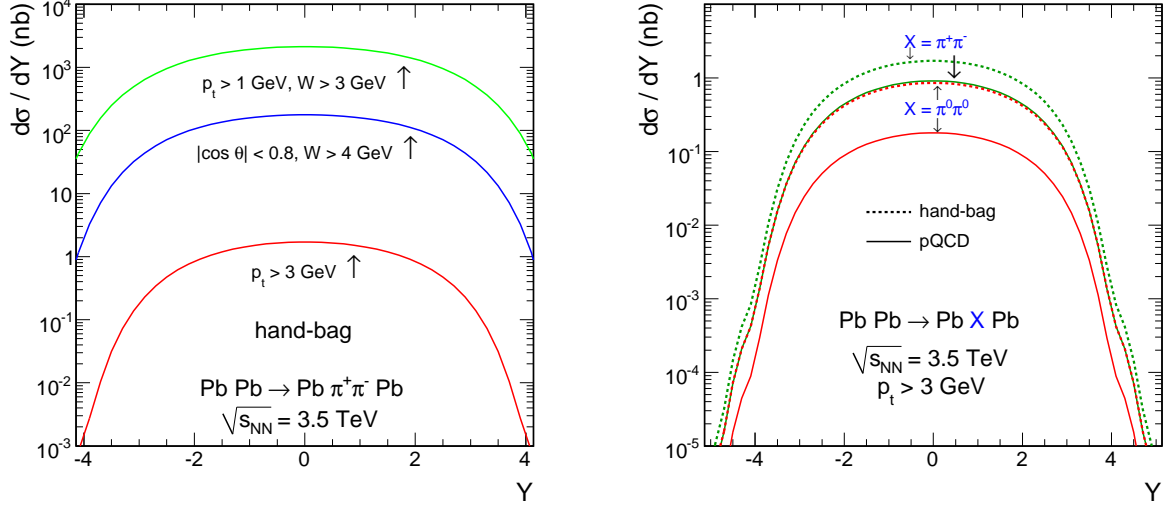
FIG. 10: The pion pair rapidity distribution. The left panel shows the result for the hand-bag model for different kinematic regions and the right panel compares the results for BL pQCD and hand-bag approaches for $p_t > 3$ GeV, i.e. region not accessible so far in the e^+e^- collisions.

integrated cross section with cuts as well as study the ratio for $\pi^0\pi^0$ to $\pi^+\pi^-$ as a function of accessible kinematical variables.

IV. CONCLUSIONS

In the present paper we have discussed a possibility to study the $\gamma\gamma \to \pi\pi$ processes in ultraperipheral ultrarelativistic heavy-ion collisions.

In the present paper we have concentrated on the large two-pion invariant masses. First, we show how different reaction mechansims describe the large photon-photon energy data. We have discussed the pQCD Brodsky-Lepage mechanism with the distribution amplitude used recently to describe the pion transition form factors measured by the BABAR collaboration. For comparison we have considered the soft hand-bag mechanism proposed by Diehl, Kroll and Vogt. In addition we have considered also t and u channel ω meson exchanges. In our opinion the situation in the measured energy range $\sqrt{s_{\gamma\gamma}} < 4$ GeV is not clear.

The elementary cross sections have been used to make predictions for the exclusive production of pionic pairs in heavy-ion collisions. In order to concentrate on the interesting region where the pQCD may apply we have imposed cuts on pion angles in the dipion center of mass and on the pion transverse momenta. In addition, this allows to get rid of the soft and resonance regions. In the present paper we have presented predictions for the present LHC energy $\sqrt{s_{NN}} = 3.5$ TeV. The distributions in the two-pion invariant mass and pion-pair rapidity have been calculated and shown.

Both the STAR collaboration at RHIC and the ALICE collaboration at LHC could measure the cross section for the exclusive $\pi^+\pi^-$ production not only in the perturbative region. The region of resonances can be measured already with low statistics. Since the cross section for large invariant masses is smaller it requires good statistics. Having the absolutely normalized cross sections is very important in this context. In general diffractive nuclear

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photon-pomeron mechanism can also contribute to the discussed region. Such a process is naively enhanced in nuclear collisions only by the Z^2 factor compared to the Z^4 factor for the mechanism discussed here. A real comparison to future data will require inclusion of the mechanism too. This goes, however, beyond the scope of the present analysis and requires further development in understanding nuclear diffractive processes. This is on our list of the topics of interest.

[1] V. M. Budnev, I. F. Ginzburg, G. V. Meledin and V. G. Serbo, Phys Rep. **15C** (1975) 181; F. Krauss, M. Greiner, and G. Soff, Prog. Part. Nucl. Phys. **39** (1997) 503; G. Baur, K. Hencken, and D. Trautmann, J. Phys. **G24** (1998) 1657; G. Baur, K. Hencken, D. Trautmann, S. Sadovsky, and Y. Kharlov, Phys. Rep. **364** (2002) 359; C. A. Bertulani, S. R. Klein, and J. Nystrand, Annu. Rev. Nucl. Part. Sci. **55** (2005) 271; A. J. Baltz et al., Phys. Rep. **458** (2008) 1.

[2] M. Kłusek, A. Szczurek, and W. Schäfer, Phys. Lett. **B674** (2009) 92.

[3] M. Kłusek-Gawenda and A. Szczurek, Phys. Rev. **C82** (2010) 014904.

[4] M. Kłusek-Gawenda, A. Szczurek, M. V. T. Machado and V. G. Serbo, Phys. Rev. **C83** (2011) 024903.

[5] M. Łuszczak and A. Szczurek, arXiv: 1103.4268 [nucl-th].

[6] N. N. Achasov and G. N. Shestakov, arXiv: 0905.2017 [hep-ph].

[7] J. Bijnens and F. Cornet, Nucl. Phys. **B296** (1988) 557; J. F. Donoghue, B. R. Holstein and Y. C. Lin, Phys. Rev. **D37** (1988) 2423; J. F. Donoghue and B. R. Holstein, Phys. Rev. **D48** (1993) 137; S. Bellucci, J. Gasser and M. E. Sainio, Nucl. Phys. **B423** (1994) 80; J. A. Oller and E. Oset, Nucl. Phys. **A629** (1998) 739; L. V. Fil'kov and V. L. Kashevarov, Phys. Rev. **C72** (2005) 035211; J. Gasser, M. A. Ivanov, M. E. Sainio, Nucl.Phys. **B745** (2006) 84; J. A. Oller and L. Roca, Eur. Phys. J. **A37** (2008) 15; L. V. Fil'kov and V. L. Kashevarov, Phys. Rev. **C81** (2010) 029801.

[8] N. N. Achasov and G. N. Shestakov, Phys. Rev. **D77** (2008) 074020; N. N. Achasov and G. N. Shestakov, JETP Lett. **88** (2008) 295.

[9] P. Ko, Phys. Rev. **D41** (1990) 1531.

[10] G. Mennessier, S. Narison and X.-G. Wang, Nucl.Phys.Proc.Suppl.207-208: (2010) 177.

[11] V. P. Goncalves and M. V. T. Machado Phys. Rev. **C80** (2009) 054901.

[12] S. J. Brodsky and G. P. Lepage, Phys. Rev. **D24** (1981) 1808.

[13] C. R. Ji and F. Amiri, Phys. Rev. **D42** (1990) 3764.

[14] B. Nizic, Phys. Rev. **D35** (1987) 80.

[15] ALEPH Collaboration, A. Heister et al., Phys. Lett. **B569** (2003) 140.

[16] Belle Collaboration, H. Nazakawa et al., Phys. Lett. **B615** (2005) 39.

[17] G. Duplancic and B. Nizic, Phys. Rev. Lett. **97** (2006) 142003.

[18] BaBar Collaboration, B. Aubert, et al., Phys.Rev. **D80** (2009) 052002.

[19] X. G. Wu and T. Huang, Phys. Rev. **D82** (2010) 034024.

[20] M. Diehl, P. Kroll and C. Vogt, Phys. Lett. **B532** (2002) 99; M. Diehl and P. Kroll, Phys. Lett. **B683** (2010) 165.

[21] A. Szczurek and J. Speth, Eur. Phys. J. **A18** (2003) 445.

[22] A.V. Efremov and A. V. Radyushkin, Phys. Lett. **B94** (1980) 245.

[23] S. J. Brodsky and G. P. Lepage, Phys. Lett. **B87** (1979) 359.

[24] D. Müller, Phys. Rev. **D51** (1995) 3855.

[25] E. R. Arriola and W. Broniowski, Phys. Rev. **D66** (2002) 094016.

[26] V. L. Chernyak, Phys. Lett. **B640** (2006) 246.

[27] V. L. Chernyak and A. R. Zhitnitsky, Nucl. Phys. **B201** (1982) 492.

[28] A. Sibirtsev, J. Haidenbauer, H.-W. Hammer, S. Krewald and U.-G. Meißner, Eur. Phys. J. **A45** (2010) 357.

[29] Belle Collaboration, S. Uehara et al., Phys. Rev. **D78** (2008) 052004.

[30] CELLO Collaboration, H. J. Behrend et al., Zeit. Phys. **C52** (1992) 381.

[31] CLEO Collaboration, J. Dominick et al, Phys. Rev. **D50** (1994) 3027.

[32] Gamma Collaboration, H. Aihara et al., Phys. Rev. Lett. **57** (1986) 404.

[33] Mark II Collaboration, J. Boyer et al., Phys. Rev. **D42** (1990) 1350.

[34] VENUS Collaboration, F. Yabuki et al., J. Phys. Cos. Jap. **64** (1995) 435.

[35] Belle Collaboration, S. Uehara et al., Phys. Rev. **D79** (2009) 052009.

[36] Crystal Ball Collaboration, H. Marsiske et al., Phys. Rev. **D41** (1990) 3324.